ERS-1 SAR SENSITIVITY TO HYDROLOGICAL PARAMETERS: A COMPARISON WITH SIR-C AND AIRSAR DATA

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Abstract

The sensitivity of radar backscattering to surface roughness and soil moisture have been studied comparing experimental data collected with ERS-1 C-SAR, AIRSAR and SIR-C/X-SAR on Montespertoli test site (Italy) with analytical and semiempirical models. It has been found that co-polar L - band data give the highest information content for estimating soil moisture and surface roughness. At the observation parameters of ERS-1 C-SAR the sensitivity to soil moisture on a spatial scale is rather low. However, considering data collected at different dates on the same area, a very good correlation and sensitivity to soil moisture has been found.

Keywords: ERS-1, SIR-C/SAR-X, AIRSAR, Hydrology, Roughness, Soil Moisture

Introduction

The operational capability of remote sensing for monitoring hydrological parameters in large watersheds is not yet fully explored and extensive research is being carried out to evaluate the potential of microwave sensors and to assess the achievable accuracies of measurements.

A research activity, which aims at a better understanding of the information achievable from Synthetic Aperture Radar to be used in hydrology, has been carried out in Italy on the test site of Montespertoli. A significant phase of this study consists of investigating the sensitivity of radar backscattering to some important parameters (soil moisture, surface roughness, vegetation cover and biomass) which are of primary importance in modelling the geophysical processes of the hydrological cycle. Although the detection of these parameters has been the subject of many investigations, carried out in past years with ground based and airborne sensors, only a very few preliminary investigations have been carried out using data collected with spaceborne sensors, [e.g. Ref 1- 3]. A major problem in retrieving the hydrological parameters is that each of them affects the radar backscattering in a different way and separating the effects requires the use of appropriate multi-frequency polarimetric algorithms. In this paper we investigate the sensitivity of backscattering coefficient, to surface roughness and soil moisture by correlating remote sensing data to ground truth. To do that we use data collected on different dates at L- and C- bands, with ERS-1/ C-SAR, AIRSAR and SIR-C.

2.THE TEST SITE AND THE EXPERIMENT

The test site is a representative area of the landscape and climate of central Italy. About half of the area is hilly with wood, agricultural fields and some urbanization, while the remaining part is flat with agricultural fields and urbanization. In the whole site two sub areas were selected for detailed experiments:

a) an agricultural area along the Pesa river cultivated with vineyards, wheat, barley, sunflower, alfalfa and corn.

b) a subbasin of Pesa river (Virginio) where a station for the measurement of total sediment transport is located.

The area was equipped with two trihedral corner reflectors of 180 cm and one of 240 cm, deployed parallel to flight line. In addition a few homogeneous fields, whose stability and backscatter characteristics were known from previous investigations, had been specifically prepared, to be used as cross reference between flights.

Ground truth measurements included: moisture, roughness and dielectric characteristics of soils, crop maps, and vegetation parameters. Only the roughness parameters measured on profiles parallel to the observation direction (which are in this case parallel to the rows) have been taken into account for the model analysis.

	Freq. Band	Pol.	Obs. Angle	Ground res. (m)	Dates
AIRSAR	C, L, P	Quad	20° 35°- 50°	12.2 x 6.6	22-29/6 1991 14/7/91
ERS-1	C	VV	23°	30 x 26.3	29/5/92 07/8/92 24/4/94
JERS-1	L	HH	35°	18.3x24.6	24/6/92 14/4/94
SIR-C/ X-SAR	L, C, X	Quad VV	23°-55°	25x25	12-17/4, 1994 3-14/10, 1994

TABLE I: Summary of processed SAR data

The site was imaged several times between April and October, at various incidence angles by different SAR systems: the C-band ERS-1, the L-band JERS-1, and the multi-frequency polarimetric AIRSAR and SIR-C/X-SAR. Weather was dry in June when vegetation was well developed. On the contrary the average soil moisture was rather high (generally around 20%) both in April and October when most agricultural fields were bare or covered with small vegetation. A summary of data collected during the experiments is shown in TABLEI

3EXPERIMENTAL RESULTS AND DATA ANALYSIS

A comparison of calibrated ERS-1 C- band SAR data delivered by ESA/ESRIN with data collected at the same frequency and incidence angle with AIRSAR and SIR-C shows that the achieved data sets are quite consistent. As an example Fig. 1 shows the backscattering coefficient of the same fields and forests, measured at C-band, VV pol. and 23° incidence angle with AIRSAR and ERS-1. Due to the different observation dates and azimuth angle, s° of a certain crop is not the same, being related to the development stage (for wheat, barley etc.) and row directions (especially for vineyard) of vegetation. Conversely, points representing forests, which are much more stable targets, are very close to the bisecting line. This intercalibration test allowed us to combine measurements from different sensors in order to relate the backscattering to geophysical parameters.

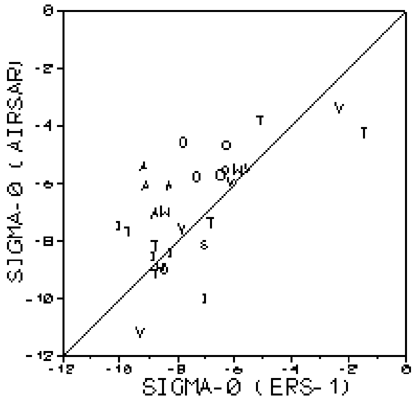

Figure 1 - *s° $_{VV}$ C-band, q = 23° measured on various cover types with ERS-1 SAR and airborne AIRSAR. (T = forest, O = oliveyard, V= vineyard, W = wheat, A= alfalfa, I = uncropped, S = sorghum)*

Surface type discrimination

The analysis of experimental data collected on Montespertoli site has shown that multifrequency radar systems are effective in separating agricultural fields from other types of surface and in discriminating among agricultural species [Ref. 3]. At P- and L-bands, there is a continuous increase of backscatter as the scatterer dimensions increase from the small leaf vegetation to the bigger forest trees. The SAR data at L-band can identify agricultural crops when they are well-developed and characterized by large stems and leaves. In particular well-developed 'broad leaf' crops, such as sunflower and corn, and plants with large stems and pods, such as colza,can be separated from bare soils and other crops with smaller plant constituents. The discrimination capability can be improved using C-band data. Indeed, the backscattering coefficient in this band is sensitive to small stems and leaves too. A simple algorithm which uses combined polarimetric data at P-, L and C-bands has been developed and tested with data collected with ERS-1/C-SAR, AIRSAR, SIRC-C and JERS-1/L-SAR. Nine classes have been separated: urban area, water body, forest, vineyards, olive groves, bare soil, sunflower, colza, and a class of mixed vegetation including wheat, alfalfa and pastures [Ref. 4]

Sensitivity to surface roughness

Since our data base includes data from P to X band at various polarization and incidence angles, we have investigated the influence of frequency, polarization and incidence angle on the response of various surface types. The highest sensitivity to soil roughness, at least in the investigated range of height standard deviations, has been noticed at L-band, copol, and q = 35° - 50° [Ref.5]. A comparisons of experimental data with theory has been carried out considering direct relations between the backscattering coefficient and the surface roughness and soil moisture content. Since the degree of roughness of a surface is defined in terms of electromagnetic wavelength, a typical parameter used to investigate the variations of the backscattering coefficient with roughness is the product (*ks*) of the height standard deviation *s* with the wave number *k* (k = 2p/l, l = electromagnetic wavelength).

Experimental data have been compared with the Integral Equation Model [Ref. 6] implemented for single scattering. In the model the dielectric constant of soil was simulated by using a polynomial fit [Ref. 7], we assumed a soil with a mean value of texture (70% sand and 30% silt+clay), moisture SMC = 20 % and an exponential autocorrelation function with a correlation length l = 6 cm. Fig. 2 shows that the model (continuous line) reproduces quite well the data up tp *ks* = 2 where multiple scattering effects can be neglected. It should be noted that, whereas at L-band s° gradually increases with ks, at C-band the saturation confirms that the same surface may appear rougher at C- than at L-band.

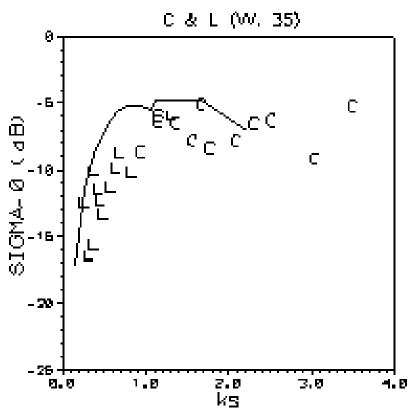

Figure 2 *- s°$_{VV}$ at L- [L] and C-[C] band, q = 35° (AIRSAR + SIR-C) as a function of ks. Continuous line represents the IEM model computed for l = 6 cm and SMC = 20 %.*

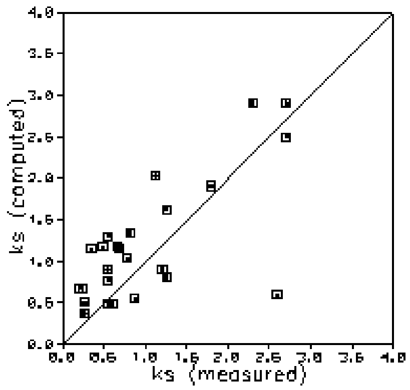

Figure 3 *- Comparison of the retrieved and measured height standard deviation (normalized to wavelength)*

According to a semiempirical model developed by Oh et al. [Ref. 8] the parameters p = s°$_{HH}$/s°$_{VV}$ and q = s°$_{HV}$/s°$_{VV}$ can be related to k*s*, and to soil reflectivity G. The latter parameters can be retrieved with a satisfactory accuracy provided 0.1<ks<6 and 2.6<kl<19.7. Once G has been retrieved the correspondent soil moisture value can be computed trough an appropriate model [Ref.9]. The comparison between measured and retrieved height standard deviation of surface roughness is shown in Fig.3. We see that, in spite of some overestimation the obtained result appears rather satisfactory.

Sensitivity to soil moisture

The sensitivity of a radar signal to moisture of smooth bare soils has been proven in many experiments carried out over the past years [Ref. 9]. However the radar signal is strongly influenced by surface roughness and vegetation cover as well, and separating the effects is not an easy task. The spurious effects are reduced for observation at incidence angle close to the nadir, but in this case the quality of SAR images is affected by the poor spatial resolution. According to data collected at Montespertoli, the highest correlation (r^2 = 0.63) and sensitivity (0.66 dB/ % SMC) to soil moisture is at L-band, HH pol., q ~ 20° (Fig. 4).

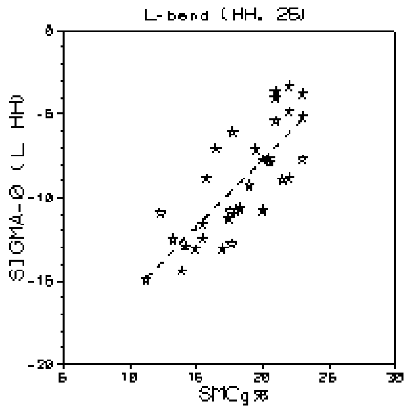

Figure 4*- s°$_{HH}$ at L-band, q = 25° (AIRSAR + SIR-C) as a function of SMC of bare and scarcely vegetated (plant water content < 1 Kg/m^2) fields*

A direct comparison of ERS-1 and SIR-C C-band backscatter with soil moisture of single fields shows that the correlation is rather low (r^2 = 0.4) (Fig. 5).

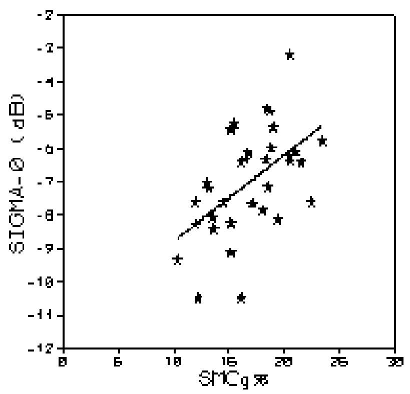

Figure ***5*** *- s°$_{VV}$ at C-band, q= 23° (ERS-1 + SIR-C), as a function of SMC of bare and scarcely vegetated (plant water content < 1 Kg/m^2) fields.*

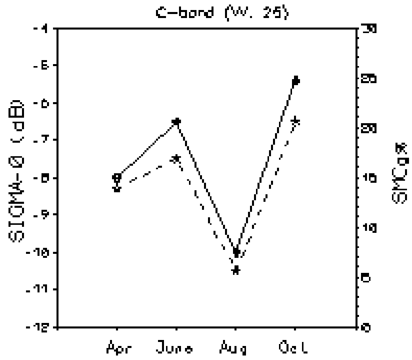

Figure 6 *- s°$_{VV}$ at C- band, q = 23° (ERS-1 + SIR-C) (continuous line) and SMC (dotted line) of an area comprising 20 bare or scarcely vegetated fields as a function of time.*

However, comparing data collected at different dates with ERS-1, SIR-C and AIRSAR (fig. 6), on the same area which includes twenty bare or scarcely vegetated fields, the correlation significantly increases (r^2 = 0.9). The average value of s° increases of about 5 dB as the SMC (gravimetric) increases from 5 % to 20%, which correspond to a sensitivity of 0.3 dB per % gravimetric soil moisture. A similar result has been obtained at L- band HH pol, q = 25° with AIRSAR and SIR-C data.

4.FINAL REMARKS

The analysis carried on Montespertoli site using multi-frequency, multitemporal SARdata indicate that:

- multifrequency radar systems are quite effective in separating agricultural fields from other kinds of targets and in discriminating among agricultural species.

- in the scale of surface roughness typical of agricultural areas, a co-polar L- band sensor observing at two incidence angles (close to 20° and 35°/50°) gives the highest information content for estimating soil moisture and surface roughness.

- at the observation parameters of ERS-1 C-SAR the sensitivity to soil parameters on a spatial scale is rather low. However, considering data collected at different dates on the same area, the correlation and sensitivity to soil moisture is significant.

- good agreement has been found between experimental data and simulations with Integral Equation Model

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